Graphene Properties and Physics

I. Introduction

- Graphene is a flat monolayer of carbon atoms tightly packed into a two-dimensional (2D) honeycomb structure.
- Graphene has many superior properties to that of silicon making it a better choice for the Nano electronics industry.

II. Graphene as a material

- It is the one-atom thick planar sheet of carbon atoms, which makes it the thinnest material ever discovered.
- The carbon-carbon bond length in graphene is about 0.142nm.
- Graphene is the basic structural element of some carbon allotropes including graphite, charcoal, carbon nanotubes & fullerences.
- It can be wrapped up into **0D** fullerences, rolled into **1D** nanotube or stacked into **3D** graphite.
- Graphene is highly conductive for both heat & electricity.
- It is almost completely transparent, yet so dense that not even helium can pass through it.
- Higher operating frequency due to less charge storage time.
- Graphene is two dimensional allotrope of carbon, while silicon is single dimensional metalloid found in nature.

III. Chemical Properties of Graphene to Silicon

- Graphene has no band gap unlike silicon which has a band gap.
- Graphene is considered metal & semiconductor hybrid, Silicon is pure semiconductor.
- Doping of graphene is divided into three categories
    1. Hetero atom doping
    2. Chemical modification strategy
    3. Electrostatic field tuning
- Doping of silicon is divided into two categories
    1. p-type
    2. n-type

IV. Electrical Properties of Graphene & Silicon

- Break-over voltage of graphene is less than 0.3V while that of silicon is 0.3 Volts.
- Graphene is a zero gap semiconductor so it has electron transfer 200 times faster than Silicon.
- Graphene thermal conductivity is above 4000 $W.m^{-1}.K^{-1}$, while that of silicon is 149 $W.m^{-1}.K^{-1}$
- Resistivity of the graphene sheet is 10^{-6} Ω·m while that of the silicon is 10^{3} Ω·m.
- On-off ratio of graphene is about 30 at room temperature which is six times greater than silicon.
- Graphene currently has very small voltage gain compared to silicon.
- Graphene has produced structures just 15 to 40 nanometers wide that conduct current with almost no resistance, while silicon has such structures at some micrometer wide only.
- Electrons in graphene move at speed of 300 times less than the speed of light in a vacuum.

V. Applications

1. **Graphene Transistors**
   - It still has Very poor on-off ratio, small voltage gain and operating frequencies less than 25 kHz.
   - Recently graphene transistors with an on-off ratio rate of 100GHz were created.
   - IBM had developed 10000 top gated transistors on 0.24 centimeter square chip.

2. **Carbon Nanotubes**
   - A Carbon Nanotube is a tube made entirely carbon with a diameter of about a nanometer.

3. **Integrated Circuit**
   - Its high carrier mobility & low noise allow it to be used as a channel in FETs.

4. **Ultra-Capacitors**
   - Due to incredibly high surface-area-to-mass ratio of graphene, its one potential application is in the conductive plates of ultra-capacitors.
   - Graphene can be used to produce ultra-capacitors with greater energy storage than currently available.

5. **Anti-Bacterial**
   - Graphene oxide sheets are highly effective at killing bacteria so it can be used in hygiene products.

6. **Strength Applications**
   - Graphene sheets can be used to synthesize material that's many times stronger than Kevlar.

7. **T-Ray Scanners**
   - Terahertz radiation or T-ray is used for detecting hidden objects at security checkpoints without the health risk posed by X-rays.
   - The fast frequencies generated by graphene circuits are the basis for sensors & generators of THz-range light.

8. **Heat Dissipation for electronics cooling**
   - Overheating in electronic is the main obstacle in increasing the speed of electronic products.
   - Graphene is better heat conductor, which leads to relative lower temperatures.

VI. Advantages vs. Limitations

Advantages	Limitations
Higher electron mobility.	Single sheet of grapheme is hard to produce.
Higher electric & heat conductivity than copper.	No efficient fabrication method.
Very low break-over voltage, less than 0.3V.	Due to small voltage gain, practical use is limited.
Stronger than diamond & steel.	No band gap so it can't act as a switch.
Transparent & very dense.	
Can be used to make anti-bacterial materials as well as bio devices.	
Can make very light weight parts for auto bodies & armors.	

VII. Conclusion

- Graphene is a material which has the capability to eliminate the current semiconductors such as silicon and form a new era of superfast microelectronics.
- The most likely applications for Graphene will be in analogue systems, such as radar, satellite communication and imaging devices.